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M.F. PROPAGATION: the reduction of interference by the use of horizontal-dipole transmitting aerials

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RESEARCH DEPARTMENT

M.F. PROPAGATION: THE REDUCTION OF INTERFERENCE BY THE USE OF HORIZONTAL-DIPOLE TRANSMITTING AERIALS

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June 1972

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Summary

Horizontal aerials are sometimes used for sky-wave broadcasting at medium frequencies. Interference is reduced as a result, because the power radiated at low angles by horizontal aerials is much less than that radiated by vertical aerials. The reduction may, however, be overestimated if the ground in the vicinity of the aerial is assumed to be perfectly conducting. The report contains curves which enable field strengths resulting from the use of horizontal aerials above ground of various conductivities to be estimated from propagation curves published by the CCIR.

1. Introduction

During the night, horizontal-dipole aerials may be used at medium frequencies (m.f.) for sky-wave broadcasting. They may radiate vertically upwards to serve the area around the transmitter[1] or obliquely to serve an adjacent area. In either case the effective radiated power (e.r.p.) at low angles is much less than it would be if the same power were radiated from a vertical aerial. A worthwhile reduction of co-channel interference may therefore be achieved.

The reduction of interference at distances greater than 1000 km was discussed in an earlier report,[2] which showed that it is completely determined at the transmitting end of the path by the e.r.p. reduction and change of polarisation coupling loss. The present report considers in greater detail how the e.r.p. reduction is influenced by imperfect ground conductivity, especially in the 'end-on' directions from horizontal dipoles, where the radiation is vertically polarised. Curves in the earlier report showed the change of polarisation coupling loss which arises when horizontal polarisation is radiated instead of vertical polarisation. These curves have been redrawn to enable them to be used as corrections to existing propagation curves.[3]

2. E.R.P. reduction with a horizontal dipole

When the powers radiated at low angles from horizontal and vertical aerials are compared, allowances must be made for the effect of the ground, as imperfect ground conductivity on the first part of the propagation path reduces low-angle radiation from vertical aerials; this effect is referred to as ground loss.[4] If the ground loss associated with a vertical aerial is disregarded when it is being compared with a horizontal aerial, the reduction of low-angle radiation resulting from the use of the horizontal aerial will be overestimated.

For planning purposes it is convenient to use the EBU/CCIR sky-wave propagation curves[3] and to apply corrections when horizontal aerials are used. Since the EBU/CCIR curves were derived from measurements made with vertical transmitting aerials, they already include a certain amount of ground loss which must be allowed for.

The ground loss inherent in the EBU/CCIR curves may be calculated by assuming an effective ground conductivity of 10^{-2} S/m. This conductivity, which is slightly greater than that of average land, takes account of the fact that the initial parts of some of the paths over which the EBU measurements were made were over the sea.

If a short vertical aerial surrounded by ground of this conductivity is compared with a horizontal aerial radiating the same power, the changes in e.r.p. at low angles may be regarded as corrections to be applied to the basic EBU/CCIR ionospheric propagation curves.* In general these corrections will depend on the conductivity of the ground in the vicinity of the horizontal aerial. In the plane perpendicular to a horizontal dipole, however, the correction is almost independent of ground conductivity because the Fresnel reflection coefficient for horizontally-polarised radiation is approximately equal to −1 for all ground con-

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* Although the EBU/CCIR curves are drawn for a semi-iostropic source giving a field strength of 300 mV/m at a distance of 1 km, they are valid at low angles for short vertical aerials radiating 1 kW.

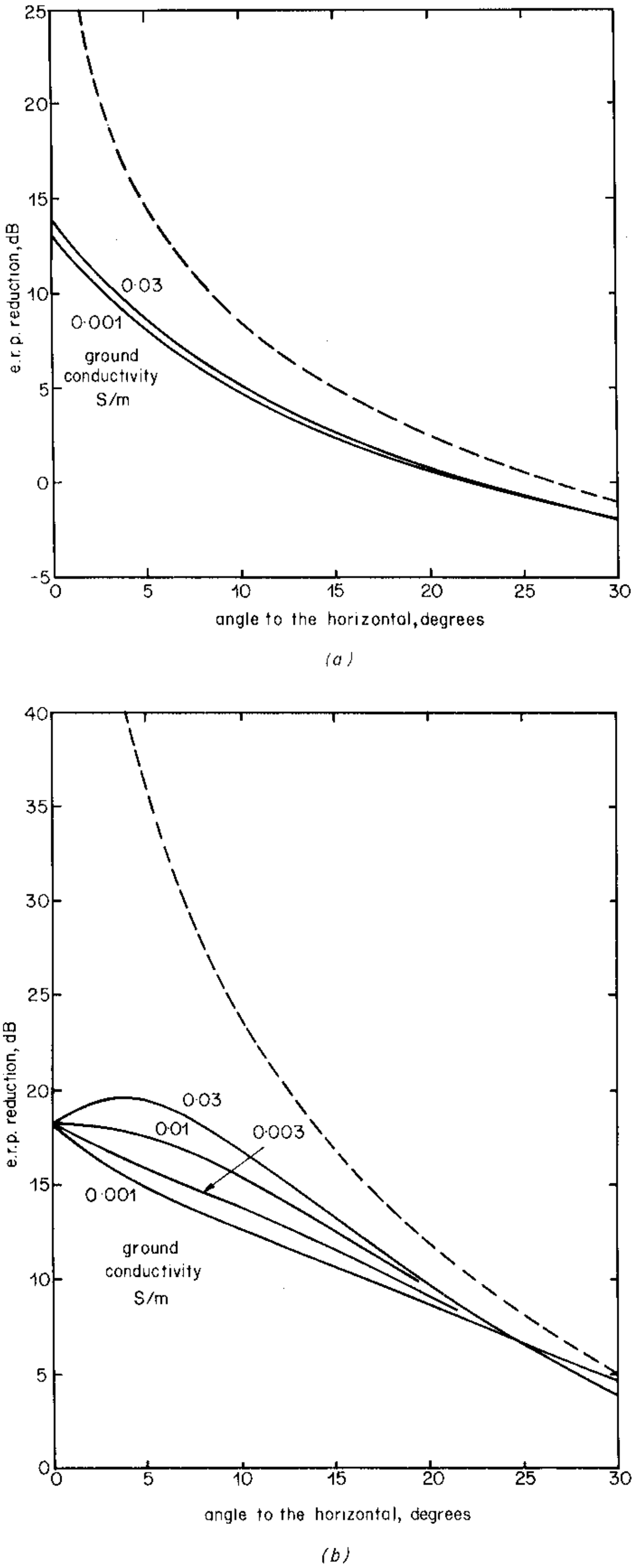

Fig. 1 - E.R.P. corrections for a horizontal dipole
(*a*) plane perpendicular to dipole (*b*) plane containing dipole
Height of dipole above ground, λ/4 Frequency 1·5 MHz
——— Corrections for EBU/CCIR curves
— — — — E.R.P. reduction for perfectly-conducting ground

ductivities. Fig. 1(*a*) shows correction curves for low angles in this plane for a horizontal half-wave dipole 0·25λ above ground; curves for single dipoles at heights up to 0·5λ do not differ significantly. A frequency of 1·5 MHz is assumed since the higher frequencies in the m.f. band are more likely to be used for horizontal aerials than are the lower frequencies, but correction curves for other frequencies would be similar. Different corrections, discussed in the next section, apply for horizontal-dipole arrays.

In the 'end-on' directions, radiation from horizontal dipoles is vertically polarised and indistinguishable from that due to vertical aerials. Imperfect ground conductivity reduces low angle radiation from vertical aerials but has the opposite effect in the 'end-on' directions from horizontal aerials. The combined effect of ground loss with vertical aerials and 'ground gain' with horizontal aerials significantly reduces the suppression of co-channel interference which would be achieved in the 'end-on' directions if the ground were perfectly conducting. The presence of an earth system below the aerial has negligible effect on low-angle radiation.

Fig. 1(*b*) shows corrections to the EBU/CCIR curves for radiation in the 'end-on' directions from the horizontal dipole previously described. Although the corrections depend to some extent on the conductivity of the ground near the aerial, they tend to a limiting value at low angles. Corrections for other frequencies and for aerial heights up to 0·5λ are again similar.

In all other directions, horizontal aerials radiate both vertical and horizontal polarisation and the resultant wave is elliptically polarised. The e.r.p. is then equal to the sum of the e.r.p.s of the horizontal and vertical components. Fig. 2 shows corrections to the EBU/CCIR curves as a function of azimuth, for an angle of elevation of 5°. The method of calculation is described in Appendix 1.

The broken lines in Figs. 1 and 2 show the e.r.p. reductions which would result if a vertical aerial over perfectly-conducting ground were replaced by a horizontal aerial. If the e.r.p. reductions given by the broken lines were applied to the EBU/CCIR curves, the levels of co-channel interference from horizontal transmitting aerials would be underestimated by an amount equal to the difference between the broken and full lines. In the 'broadside' directions the error is approximately equal to the ground loss for the vertical reference aerial assumed for the EBU/CCIR curves. In the 'end-on' directions the error may be as much as 20 dB.

In applying the correction curves contained in Figs. 1 and 2 to specific paths, the take-off angles of the dominant propagation modes must first be determined by taking account of the frequency, the path length and the time after sunset. For take-off angles less than 1° the corrections may be slightly in error because no allowance has been made for the diffraction of vertically-polarised waves around the surface of the Earth. Waves propagated at angles below 1° do not, however, normally contribute significantly to received signals.

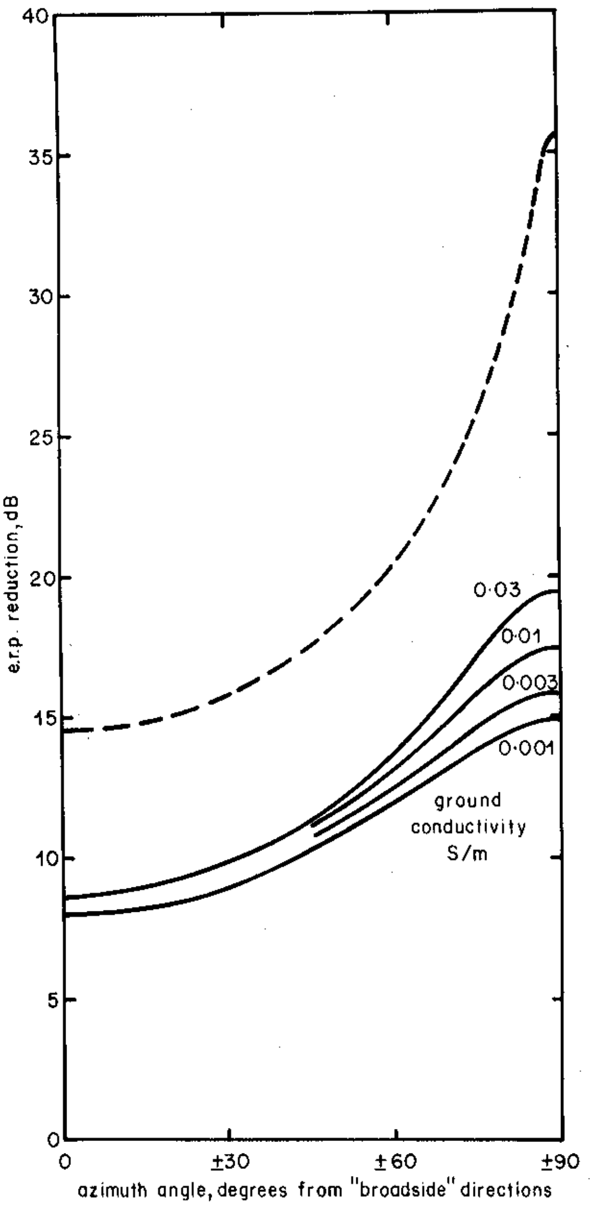

Fig. 2 - E.R.P. corrections for a horizontal dipole
Angle of elevation 5° Height of dipole above ground, λ/4
Frequency 1·5 MHz
——— Corrections for EBU/CCIR curves
– – – – E.R.P. reduction for perfectly-conducting ground

3. E.R.P. reduction with an array of horizontal dipoles

Additional suppression of low-angle radiation from horizontal aerials can be achieved by using a horizontal array of dipoles. An array which has been described[1] consists of four horizontal half-wave dipoles 0·2λ above ground with their centres forming a 0·5λ square. The additional suppression obtained by replacing a single horizontal dipole by an array at the same (or similar) height above ground may be calculated by comparing the radiation patterns of the two aerials in free space. Allowance must, of course, be made for the fact that the currents in the array dipoles are less than that in the single dipole when the same power is radiated.

Fig. 3 shows the additional suppression achieved by the array described; details of the calculation are also given in Appendix 1. At low angles the additional suppression is very high in the 'broadside' and 'end-on' directions because the dipoles are spaced 0·5λ, and it is least at 45° to these directions.

4. Polarisation coupling loss

The EBU/CCIR sky-wave propagation curves were derived from measurements of transmissions from vertical aerials in Europe and it may be shown that the average polarisation coupling loss for one-hop low-angle paths in Europe is about 2 dB.[5] Field strengths derived from the EBU/CCIR curves for distances served by low-angle one-hop modes therefore include an average polarisation coupling loss of 1 dB at each end of the path.

If a horizontal transmitting aerial is used, an allowance must be made for the change of polarisation coupling loss in the directions in which horizontal polarisation predominates, and curves showing the change of polarisation coupling loss which arises when horizontal polarisation replaces vertical polarisation have been published.[2] For planning

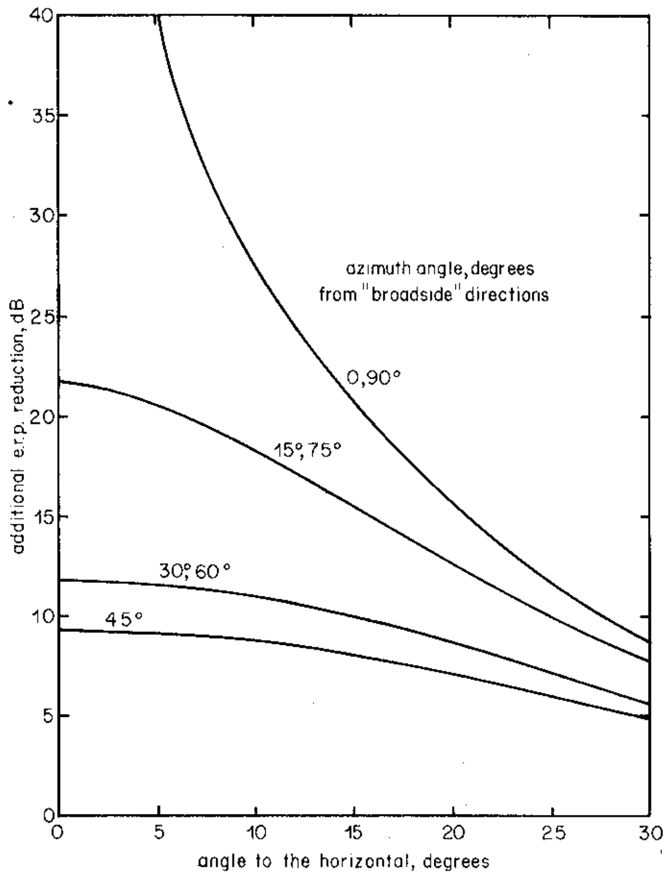

Fig. 3 - Additional e.r.p. reduction for an array of four horizontal dipoles. The centres of the dipoles form a 0·5λ square

purposes, however, it is more convenient to use correction curves which may be applied directly to the basic EBU/CCIR ionospheric propagation curves. Fig. 4 shows representative curves, calculated by the method described in Appendix 2, for a wave frequency equal to the gyromagnetic frequency (1·2 to 1·3 MHz in Europe) and an angle of incidence at the D layer of 80°; this angle corresponds to a ground elevation angle of 5° and a one-hop path length of 1500 km. The curves are approximately correct for all frequencies in the m.f. band and for ground elevation angles up to 15°. Fig. 4 shows that the field strengths derived from the EBU/CCIR curves may be reduced by 4 to 12 dB in European latitudes, in the particular directions in which horizontal polarisation is radiated.

Fig. 4 applies only within ±20° of the 'broadside' directions, where the radiation is essentially horizontally polarised. In the 'end-on' directions, radiation from horizontal aerials is vertically polarised and polarisation coupling loss corrections are not required in Europe. Corrections identical to those required for vertical aerials would, however, have to be applied in tropical latitudes. In all other directions radiation from horizontal aerials is elliptically polarised and the polarisation coupling loss could range from zero to a very large value. The precise value depends both on the orientation of the aerial and on the direction of propagation and could be calculated exactly for specific propagation paths. In the absence of an exact calculation it is safest in Europe to assume that the polarisation coupling loss is small and to make no correction to the EBU/CCIR curves.

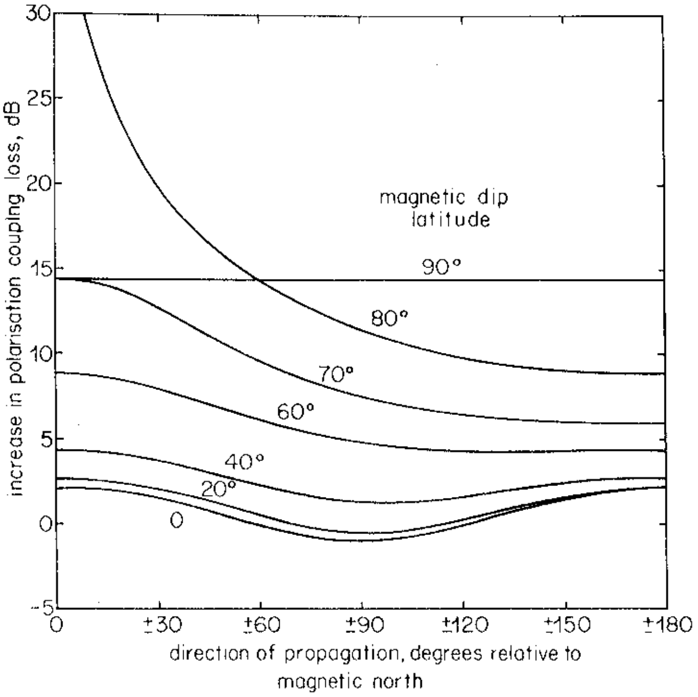

Fig. 4 - Polarisation coupling loss correction for horizontally-polarised radiation

5. Conclusions

Although a significant reduction in co-channel interference can be achieved if a horizontal transmitting aerial is used in place of a vertical aerial, the reduction may be overestimated by as much as 20 dB if it is derived from comparisons between theoretical radiation patterns for aerials over perfectly-conducting ground. The error arises because imperfect ground conductivity not only reduces low-angle radiation from vertical aerials but also increases low-angle radiation from horizontal aerials in certain directions.

Co-channel interference levels are also influenced by changes of polarisation coupling loss. Radiation from horizontal aerials is essentially horizontally polarised within ±20° of the 'broadside' directions and the change of polarisation coupling loss may be derived from curves contained in this report. Vertical polarisation is radiated in the 'end-on' directions and here the polarisation coupling loss is unchanged. In all other directions, radiation from horizontal aerials is elliptically polarised and polarisation coupling loss depends on several factors. If it cannot be calculated exactly, the effect of a different polarisation coupling loss should be disregarded in order to avoid underestimating co-channel interference when using the EBU/CCIR ionospheric propagation curves.

For a given total power radiated, the use of a single horizontal dipole in place of a short vertical aerial reduces the level of co-channel interference on medium and long distance paths in Europe by about 15 dB in most directions. Greater suppression can be achieved by using more complicated aerials; for example, the use of an array of four dipoles on a 0·5λ square gives considerable additional suppression at low angles, especially in the 'broadside' and 'end-on' directions.

6. References

1. EBERT, W. 1970. Mittelwellen-Steilstrahlung unter besonderer Berücksichtigung der Frequenz 1562 kHz. *Tech. Mitt. PTT*, 1970, **48**, 6, pp. 237 – 257.

2. KNIGHT, P. Medium-frequency sky-wave broadcasting: effect of polarisation on interference. BBC Research Department Report 1970/7. Also in *EBU Rev.*, 1971, **125—A**, pp. 15 – 17.

3. Sky-wave propagation curves between 300 km and 3500 km at frequencies between 150 kHz and 1600 kHz in the European broadcasting area. CCIR Report 264-2, New Delhi, 1970, Volume II, Part 2, pp. 124 – 140.

4. KNIGHT, P. *and* THODAY, R.D.C. 1969. Influence of the ground near transmitting and receiving aerials on the strength of medium-frequency sky-waves. *Proc. IEE*, 1969, **116**, 6, pp. 911 – 919.

5. PHILLIPS, G.J. *and* KNIGHT, P. 1964. Effects of polarisation on a medium-frequency sky-wave service, including the case of multihop paths. *Proc. IEE*, 1965, **112**, 1, pp. 31 – 39.

6. Diagrammes d'antenna, CCIR, Geneva, 1953.

7. APPENDIX 1:
E.R.P. corrections for horizontal aerials

Figs. 1 and 2 show the changes in e.r.p. which take place when a short vertical aerial is replaced by a horizontal aerial radiating the same power. The short vertical aerial is assumed to be surrounded by ground having a conductivity of 10^{-2} S/m, for reasons stated in Section 2.

The vertical radiation pattern of the vertical aerial is given by

$$E_R = 150(1 + \rho_v)\cos\alpha \tag{1}$$

where ρ_v is the Fresnel plane-wave reflection coefficient for vertical polarisation and α is the angle to the horizontal. Equation (1) neglects the surface wave, since this makes no contribution to interfering sky-wave field strengths, and it gives the field strength in mV/m at a distance of 1 km. The radiation is vertically polarised and independent of azimuth.

Radiation from horizontal aerials is, in general, elliptically polarised and varies both with azimuth and elevation. The radiation pattern depends on the number of dipoles and on their height above ground.

The horizontally-polarised component of the radiation pattern of the single dipole considered in Section 2 is given approximately* by

$$E_H = 206 \cos\phi \left[e^{j\frac{\pi}{2}\sin\alpha} + \rho_H e^{-j\frac{\pi}{2}\sin\alpha} \right] \tag{2}$$

where ϕ is the azimuth angle, measured from the plane perpendicular to the dipole (the 'broadside' directions) and ρ_H is the Fresnel plane-wave reflection coefficient for horizontally-polarised waves, approximately equal to -1. The constant in Equation (2) is derived from published data.[6]

The vertically-polarised component is given approximately* by

$$E_v = 206 \sin\phi \sin\alpha \left[e^{j\frac{\pi}{2}\sin\alpha} - \rho_v e^{-j\frac{\pi}{2}\sin\alpha} \right] \tag{3}$$

The e.r.p. of the aerial in the direction α, ϕ is proportional to $|E_H|^2 + |E_v|^2$. Figs. 1 and 2 show the ratio of this quantity to $|E_R|^2$, for horizontal aerials over ground of four different conductivities.

The array considered in Section 3 consists of four horizontal dipoles whose centres lie at the corners of a 0·5λ square which is 0·2λ above ground. Published data[6] gives the field strength at 1 km in the vertical direction as 680 mV/m when 1 kW is radiated. From this it may be inferred that the current in each of the dipoles is 43·4% of the current in the single horizontal dipole considered in Section 2, when the same power is radiated.

In comparing the array with the single horizontal dipole, little error arises at low angles if both are considered to be at the same height above ground. Radiation patterns and e.r.p. corrections for the array may then be derived by multiplying corresponding values for the single dipole by the array factor for four point sources forming a 0·5λ square. If the relative amplitude of the current in each source is assumed to be 0·434, it may be shown that the array factor f is given by

$$f = 1{\cdot}74 \cos\left(\frac{\pi}{2}\cos\alpha\cos\phi\right)\cos\left(\frac{\pi}{2}\cos\alpha\sin\phi\right) \tag{4}$$

Fig. 3 shows f expressed in dBs, for azimuth angles ϕ at 15° intervals and elevation angles α up to 30°.

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* Equations (2) and (3) have been simplified by assuming that the radiation pattern of a λ/2 dipole in free space is equal to $\sin\theta$, where θ is the angle from the dipole axis. This approximation introduces negligible error.

8. APPENDIX 2:
The polarisation coupling loss correction for horizontal polarisation

The polarisation coupling loss which arises when horizontally-polarised waves enter the ionosphere is given by

$$F_H = \frac{\sin^2\psi + M^2\cos^2\psi}{1 + M^2} \tag{4}$$

where M is the axial ratio of the ordinary-wave polarisation ellipse and ψ is the angle between its major axis and the vertical plane containing the direction of propagation. Formulae for calculating M and ψ are given in Reference 5.

F_H is a power ratio. Fig. 4 shows values of F_H in decibels calculated from Equation (4), reduced by 1 dB to allow for the average polarisation coupling loss inherent in the EBU/CCIR curves. Fig. 4 is intended for the Northern Hemisphere, but it may be applied to the Southern Hemisphere if the direction of propagation is measured from magnetic South.

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